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REPORT BMS45

Air Infiltration Through Windows

by

EUGENE F. COLEMAN
and ROY H. HEALD

NATIONAL
BUREAU OF STANDARDS

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BUILDING MATERIALS *and* STRUCTURES

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ISSUED APRIL 29, 1940

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Foreword

The heat losses from a building may be viewed as arising from two sources: (1) those in which the heat is transmitted through the materials comprising the walls, roof, and lower floor, thence by radiation, convection, and conduction to the outside; and (2) those in which the cold outside air enters the building by means of cracks around windows and doors, called infiltration losses.

In most cases the larger part of the total heat loss may be placed in the former classification, but a substantial part may also occur by infiltration.

This report describes test equipment for measuring infiltration of air through windows and gives the results of measurements to determine infiltration rates for several types of windows. In the work special emphasis has been placed on window types suitable for low-cost housing construction.

Lyman J. Briggs, *Director*

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ABSTRACT

Equipment for measuring the rate of infiltration of air through the clearance openings of windows and doors due to wind pressure has been developed at the National Bureau of Standards as part of the program of research on building materials and structures. By means of the equipment, tests were conducted on double-hung wood windows and light steel casements, types frequently specified for low-cost housing construction. Infiltration measurements were made for systematic sets of clearance conditions, and correlations between amount of clearance and infiltration are given. The results are summarized using a concise method for representing the relationship between air infiltration and test pressure. Relationships between average sash clearance and infiltration at the reference pressure of 0.2 in. of water are given, and a general type of relation between infiltration and pressure is suggested on the basis of the test results.

I. INTRODUCTION

The leakage of air through the outside walls of a building, including that arising from clearances around the movable members of windows and doors, is frequently an important factor in the problem of heating, cooling, and ventilating the building. In addition to the purely thermal effects of air leakage, or infiltration, the comfort which the building affords may be affected, adversely, through the formation of direct drafts and transportation of odors and dust to the interior.

The thermal effect of air infiltration furnishes a convenient index of its importance. Accepted data indicate that infiltration of cold air as a result of wind action may be responsible for 10 to 20 percent of the total rate of loss of heat in winter in conventional detached residences. Infiltration due to differences in air density may be greater than that due to very light winds. However, because of the variables and uncertainties associated with the determination of density effects, it is customary in calculating heat loss to neglect them (except in the case of tall buildings, in which the "chimney effect" due to differences in air density may become large [1] [1]) and to consider only the infiltration resulting from the action of winds having sufficiently high velocities to render the action of density differences relatively small. In either case, all but a small part of the infiltration in buildings constructed in accordance with good modern practice is due to leakage around the edges of the movable members of windows and doors.

This investigation of air infiltration is concerned with windows, to the exclusion of doors and other openings, since the total leakage perimeter of the windows in a residential building is usually at least three times, and often many times, as great as the leakage perimeter of the outside doors. As a consequence of the importance of window infiltration in heating economy, some users have formulated win-

[1] Figures in brackets occurring in the text indicate the numbered literature references at the end of this paper. Additional references are also given.

dow specifications [2] requiring either the direct measurement of infiltration in the laboratory or the measurement of the clearance spaces in the window.

The purposes of this program of research were to develop equipment for conducting air infiltration tests at the National Bureau of Standards, and to determine the relation between infiltration and sash clearances for commercially available windows of types suitable for use in low-cost housing. Analysis of the results led to the development of a concise method of representing the relationship between air infiltration and wind pressure for the various types of windows included in the tests.

Infiltration is only one of a number of factors affecting the choice and use of windows. Other pertinent considerations include ease of sash or ventilator operation, relative cost, structural durability, and appearance. Therefore, the results given in this report should not be regarded as indicative of the relative over-all merit of the types of windows tested.

In using infiltration data as a guide in design, it should be borne in mind that, except in those applications in which artificial ventilation is provided, there is no advantage to be gained by reducing the infiltration in a building below an amount determined by the need of the occupants for fresh air, since if this need is not satisfied by the existing infiltration, the air supply will be augmented by the opening of windows. Overemphasis on efforts to secure the benefits of reduced infiltration by choice of type of window is also to be avoided, since low infiltration rates may be obtained with almost any type of window by means of special sealing accessories.

II. ENGINEERING PRACTICE

1. Heat-Loss Calculation

Infiltration through windows and outside doors is responsible for an important fraction of the heat loss of a heated building in winter, the remainder of the loss occurring by thermal conduction through walls, window-glass, roof, and basement floor, and by heating-plant stack losses. In the interest of economy it is not unusual to install in a building a heating plant with a heating capacity just sufficient to maintain a desired indoor temperature under assumed conditions for maximum heat loss. In designing a heating system it is necessary, therefore, to compute an expected maximum rate of heat loss by transmission through the various parts of the building, by the heating plant, and by air infiltration.

For this purpose a hypothetical set of conditions is considered, in which the desired indoor temperature is usually taken to be in the range 68° to 72° F, the outdoor temperature is assumed to have some low winter value, and a representative wind speed is chosen. The method of selecting the outdoor temperature and the wind speed differs among various practices and is guided largely by empirical considerations. Rules recommended by one authority [1] state that the assumed outdoor temperature shall be 15° F higher than the lowest temperature on the Weather Bureau record for the locality and that the assumed wind speed shall be the arithmetic mean of Weather Bureau daily-reported wind speeds for December, January, and February in the locality.

The use of such a method will generally yield a computed rate of heat loss smaller than that due to the most adverse combination of weather conditions. However, a heating plant designed for maximun rate of heat output just equal to the computed rate of loss under the assumed conditions might be considered adequate since such abnormally cold and windy conditions occur rarely and persist for relatively short intervals. When they do occur, the probability of demand for sustained overloads on the heating plant is reduced by reason of the thermal capacity of the building and contents. When the indoor and outdoor design conditions are selected, the respective rate of heat loss from the various parts of the building (walls, roof, and glazing) may be computed by multiplying the area of each included in the building by the appropriate heat-transfer coefficients and the temperature head.

The heat losses arising from the infiltration of air through windows and doors are determined in the same general way—first, by multiplying the crack perimeter of each window or door by the infiltration coefficient appropriate to the type of window and to the selected wind

speed. The coefficients in this case are determined by laboratory tests in which a specimen window or door is subjected to measured static air pressures and the resulting air leakage through the specimen is observed. Using values of static air pressure, corresponding nominal wind speeds are derived by means of a formula discussed in the following section. The estimated rate of air leakage for the entire building, based sometimes on the entire window and door crack perimeter and sometimes on only that part of it exposed directly to the prevailing wind, is converted into equivalent heat loss by multiplying by the specific heat[2] and density of air and the temperature difference between the indoor and outdoor air.

2. Wind Pressure and Speed

In using infiltration coefficients of windows and doors, it is customary to assume the infiltration under service conditions to be due only to the pressure of the air when brought to rest at the surface of a window or door, the surface being supposed normal to the wind direction. The impact pressure, q, at the center of a fluid jet striking normally against an infinite plane surface, in terms of the fluid speed, V, and the fluid density, ρ, is equal to $\frac{1}{2}\rho V^2$, where the symbols represent values for a consistent system of units.

Standard atmospheric conditions—temperature 68° F, pressure 29.92 in. of mercury, and relative humidity 50 percent—are used in estimating infiltration for heating-plant design, the corresponding standard air density, ρ, being 0.07488 lb/cu ft (0.002327 slugs/cu ft). This value, which corresponds approximately to desired indoor temperature conditions rather than average winter outdoor temperature conditions, is ordinarily used in the impact-pressure formula. Using the value 0.002327 slugs/cu ft for ρ, the impact pressure in inches of water, q, is related to the speed in miles per hour, V, by the formula

$$q=0.000481\ V^2.$$

Since the impact-pressure formula based on the standard atmospheric conditions just described is the one generally used in infiltration work, that formula is used here and values of the pressures corresponding to various wind velocities computed from the formula are given in table 1.

Table 1.—*Computed impact pressures corresponding to various wind speeds* ($q=0.000481\ V^2$)

V	q	V	q	V	q
Miles per hour	*Inches of water*	*Miles per hour*	*Inches of water*	*Miles per hour*	*Inches of water*
2.5	0.003	25	0.301	50	1.20
5	.012	30	.434	55	1.45
10	.048	35	.590	60	1.73
15	.108	40	.770	65	2.03
20	.192	45	.975	70	2.36

Although the use of the coefficient based on indoor temperatures leads to errors that are within the tolerances usually acceptable in engineering design, special applications of infiltration data may call for the use of the coefficient suited to local outdoor air conditions.[3]

3. Selection of Wind Speed

It is recognized that the simple impact-pressure formula may fail by a substantial margin to give the wind pressure acting on windows under actual conditions, since the pressure on a particular window is dependent on the design of the building, on local wind conditions, and on the location of the window in the wall. Tests of models in the wind tunnel [3] indicate that pressures may occur ranging, for example, from a negative value of $0.8q$ on the leeward wall of a building to a positive value of about $1.0q$ on the windward wall of a building when the wind direction is normal to these walls and when the pressures are referred to the static pressure of the undisturbed wind. Since the values of these pressures are additive, the effective pressure tending to cause air to enter openings at the windward side of a building and leave through openings at the leeward side may be almost twice as great as the impact pressure $q=\frac{1}{2}\rho V^2$.

In recognition of the arbitrary character of design conditions, it is customary in computing

[2] Mean specific heat of air at constant pressure=0.24 Btu/lb.

[3] The value of ρ will differ somewhat from that used in the formula, depending on locality. For example, for air under a typical set of outdoor winter conditions, temperature 32° F, 29.61-in. barometric pressure, and 50-percent relative humidity, the air density would be 0.080 60 lb/cu ft (0.002 505 slugs/cu ft), leading to the replacement of the coefficient 0.000 481 in the formula by the coefficient 0.000 518. This value corresponds to an increase of 7.7 percent in the impact pressure for a given wind speed, or a decrease of 3.75 percent in the wind speed for a given pressure.

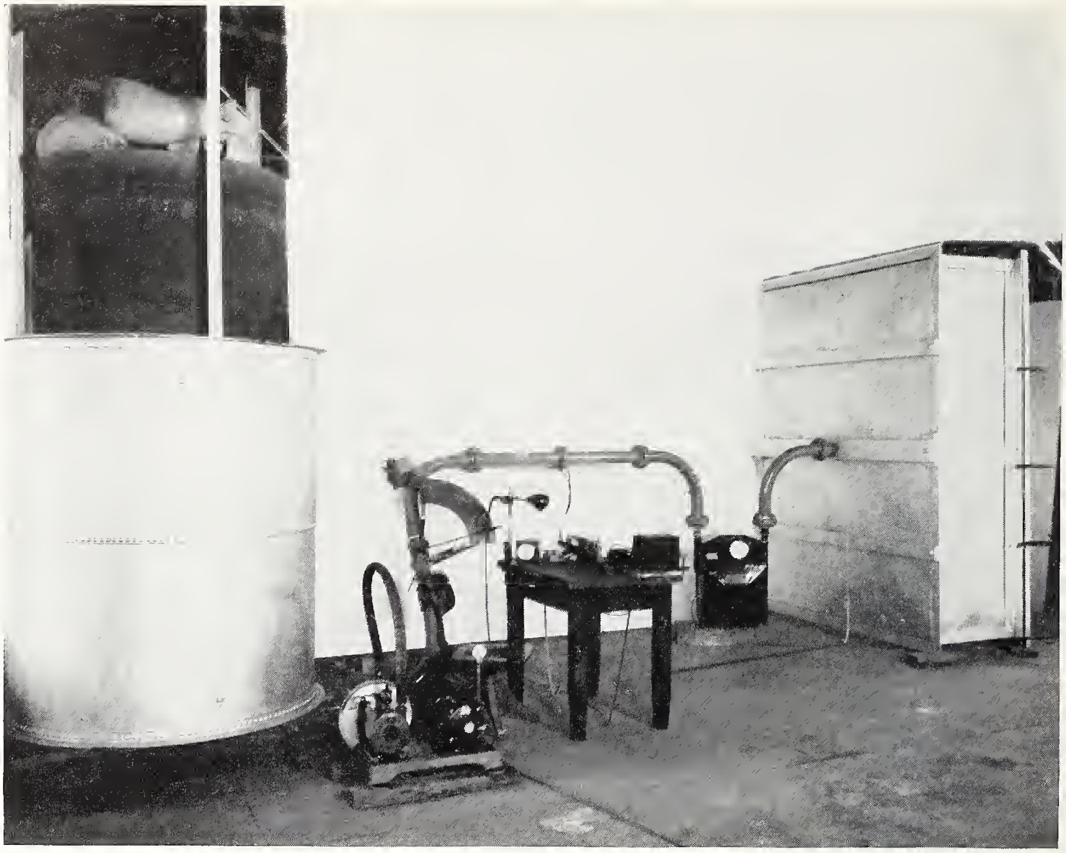

FIGURE 1.—*Test equipment.*

local air infiltration losses to make empirical allowances for the effects of building shape and of wind conditions.[4]

III. TEST EQUIPMENT

1. General Description

The infiltration test equipment developed in this project is of the single-chamber type [4], air from a gasholder being admitted directly to the pressure chamber through a pipe line. Valves for adjusting the rate of flow, together with means for metering the air and indicating the applied pressures, are provided.

The specimen window is mounted in the removable panel of the pressure chamber shown in figure 1, with the outdoor face exposed to the air pressure in the chamber. Positive pressures, adjustable up to 2 in. of water, are applied, the indoor face of the window being exposed to the atmospheric pressure of the room. After steady air-flow conditions have become established, the volume rate of leakage of the window is equal to the rate of flow of air through the meter for the pressure difference between the chamber and the room, which is measured on a manometer. A control valve in the pipe line provides accurate adjustment of pressure, up to a maximum determined by the leakage characteristics of the window, the resistance of the pipe line, and the pressure developed in the air source.

Standard 3-in. pipe and fittings are used for conducting air from the holder to the pressure chamber, which is constructed of 24-gage galvanized iron with an angle-iron frame. The dimensions of the chamber, shown in figure 2,

[4] A typical set of rules called for the use of the average wind speed for the three coldest months of the year in the locality. The following instructions regarding selection of sash perimeter were included: "In no case should the amount of sash perimeter used for computation be less than half of the total in the outside walls of the room. Thus, in a room with one exposed wall, use all the sash perimeter; with two exposed walls, use the wall having the greatest sash perimeter; but in no case use less than half the total sash perimeter. For a building having no partitions, whatever wind enters through the cracks on the windward side must leave through those on the leeward side. Therefore, use one-half the total sash perimeter for computing for each side and end of the building." [1]

are 6½ by 8½ by 2 ft. All joints are tightly soldered or sealed to prevent leakage other than that through the test specimen. The volume rate of air leakage is determined by means of a calibrated dry test gas meter of the direct read-

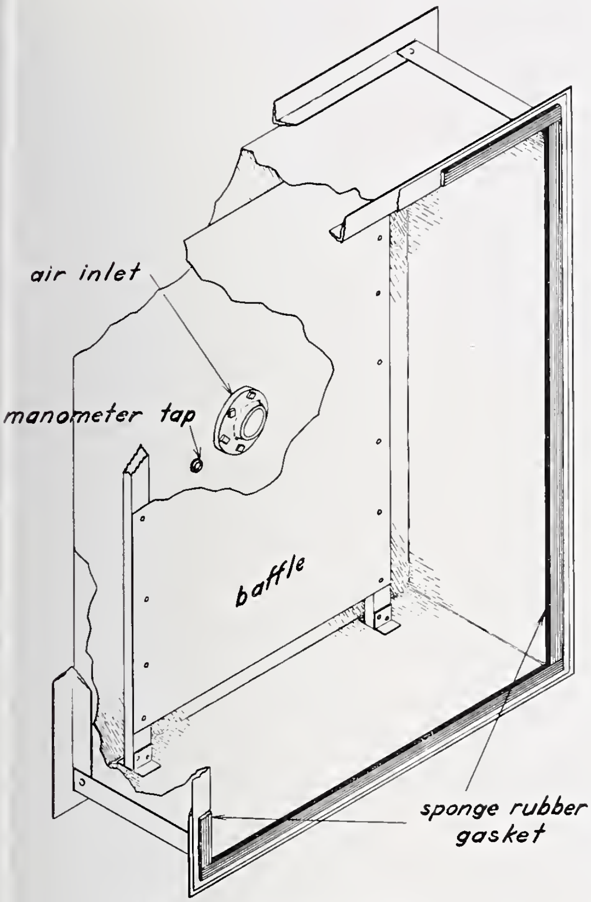

FIGURE 2.—*Pressure chamber.*

ing displacement type, provided with a special timing device.

The storage source of air is a water-seal gasholder, having a capacity of 60 cu ft, to which air is supplied by a rotary positive-displacement compressor of 13.5 cu ft/min capacity. With the bell fully weighted, the gasholder stores air at a pressure of about 10 in. of water. The flow of air is regulated by means of a 3-in. butterfly valve, the settings of which can be made rapidly and reproducibly by means of a long index arm. To avoid possible uncertainties in metering due to pulsations, the compressor is not operated while infiltration measurements are being made. Pressures in the chamber are indicated on a calibrated inclined-tube manometer reading to a maximum pressure of 3 in. of water and graduated to 0.01 in. Although, in most cases, pressures are adjusted to even hundredths of an inch while volume readings are being taken, it is possible to read the manometer to 0.001 in. Taking 0.001 in. as the limit of precision, the precision of reading the lowest pressure used in the tests (0.05 in. of water) is about 2 percent.

2. Meter Timing Equipment

The displacement gas meter indicates total volume of air transmitted, and hence must be calibrated and timed accurately in determining the average rate of infiltration. One revolution of the large hand of the meter corresponds nominally to a displacement of 10 cu. ft. and might be timed with acceptable accuracy by the use of a stop watch. In the Bureau equipment, where a large number of tests was anticipated, a semiautomatic method was used which was quite accurate and facilitated the work.[5] The wiring diagram for the timing system is shown in figure 3.

3. Test-Panel Construction

Because of the requirement of low spurious leakage, the sealing of a specimen window to the pressure chamber is an important step in the test procedure. Published test data indicate that the leakage between window frame and wall is relatively very small in modern newly constructed buildings and that it can be added to the sash leakage, so that the two can be determined by separate tests and then combined without error [5]. Accordingly, sash leakages only were determined in these tests, the frames of the specimen windows being sealed tightly into panels. Since the installation was not intended to simulate wall construction, it was

[5] A sensitive platinum-point electric contactor, normally open, is mounted on the edge of the dial of the gas meter so that a momentary contact is made by light mechanical pressure from the test hand once each revolution. Since the current flowing is only a few microamperes, contact-surface difficulties are absent. A low-lag relay system employing a small grid-glow tube and a telephone relay is controlled by the gas-meter contactor, so that it supplies energizing current to the electrically operated clutch of a synchronous timer controlled by a standard frequency signal beginning at the first momentary contact. The clutch is deenergized by the relay system at the moment of the second contact. Thus the synchronous timer indicates the time required for a nominal air-flow volume of 10 cu ft. The action of the relay system is semiautomatic.

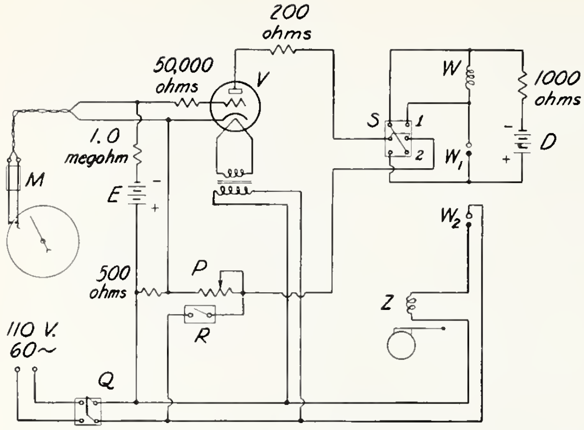

FIGURE 3.—*Meter timing circuit.*

D, 45-volt dry *B* battery. *E*, 22.5-volt dry *B* battery. *M*, contactor mounted on displacement meter. *P*, 10,000-ohm potentiometer, 25 watts; set by trial, to approximate resistance 3,000 ohms. *Q*, *R*, *S*, midget toggle switches. Plate supply switch *R* must remain open at least 30 seconds after main switch *Q* is closed, to allow cathode of tube to come to operating temperature. Switch *S* is normally in position 1, and is thrown to position 2 just after the first meter contact has been made. *V*, grid-glow tube, type 885 (RCA). *W*, 1,000-ohm telephone relay coil. W_1, W_2, relay contacts, normally open. *Z*, a-c clutch coil of electric timer.

made airtight, except for leakage around the movable members of the specimen. Lines of juncture of the panel and window frame were sealed and were, as far as possible, made identical in location with the junctures of the outside wall surface and the window frame in usual building construction. Thus, the test results represent the leakage chargeable to the window alone and are not subject to uncertainties associated with quality of workmanship in mounting and sealing the window in a wall.

The construction of a test panel and the procedure in mounting a window in it were as follows. A flat frame of 2- by 4-in. stock having the same outside dimensions as the flange of the open face of the pressure chamber was assembled, using bolted half-lap joints at the corners, and 2- by 4-in. flat framing was built inside this frame with spacing such as to enclose the window frame snugly. A drawing of a completed frame is shown in figure 4. In mounting, the test-panel frame was placed horizontally on supports, and the window frame was lowered into the inner space in the frame provided for it, with the outdoor side up, so that its weight was supported by the outside trim of the window frame, or for casement windows by the metal flange. Pieces of ¼-in. Masonite "Presdwood" or similar sheet material were fitted into place, glossed surface up, on the upper surface of the test-panel frame, to close the remaining open space around the window, and nailed down to the frame. The joints between the sheet material and the window frame were sealed by applying, while hot, an asphaltic compound developed at the Bureau for this purpose.[6]

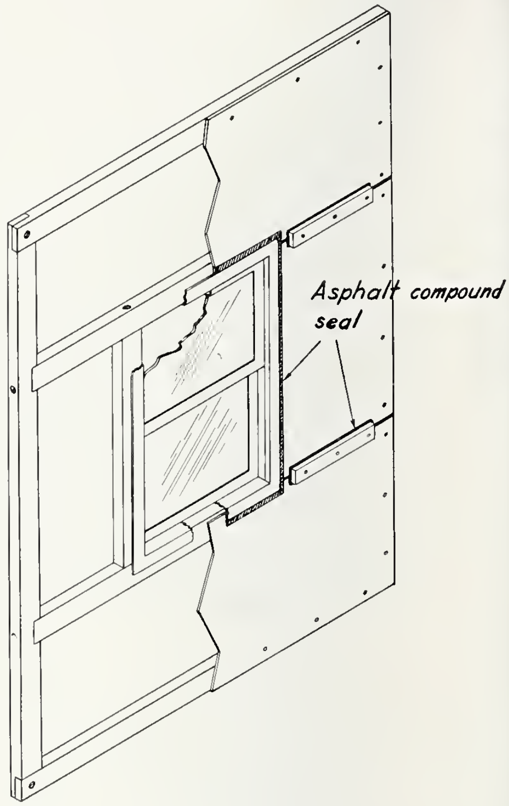

FIGURE 4.—*Test panel.*

[6] This compound was developed to satisfy the requirements of imperviousness to air, ease of application, freedom from flow and brittleness in the temperature range 40° to 100° F, and moderate cost. Several commercially available sealing compounds were tried before the development was undertaken. The composition of the compound used was as follows:

	Percent by weight
Commercial road asphalt (standard penetration 51 to 60 or 85 to 100)	52.5
Pure milled crepe rubber	2.5
Household-type paraffin (melting point 118° to 125° F)	6.0
Earth filler: any clay or ceramic powder, 100 mesh or finer	39.0
Total	100.0

For preparing the compound, the rubber is used in solution in crude benzol, 0.13 lb of rubber per quart of solution. The asphalt is melted to about the mobility of paint and the rubber solution is added slowly with stirring, the heat supply being adjusted to prevent too rapid boiling. Air is slowly passed through the mixture and heat applied until the benzol fumes are no longer detectable. Paraffin and filler are added, the filler being screened before use. The mixture is stirred vigorously and cooled quickly by placing it in moving air. It can be stored in the solid condition, and used after slow reheating to any convenient consistency for pouring. The proportion of the earth filler may be changed as desired, to alter the fluidity of the compound.

FIGURE 5.—*Light steel casement mounted in test panel.*

The face of the panel showing in the photograph is clamped against the flange of the pressure chamber during test.

The panel was completed by covering the surface with two coats of aluminum paint (2½ lb of aluminum-bronze powder per gallon of common spar varnish), which sealed over the surface of the sheet material as well as the asphaltic compound. Painting was found to be necessary because of appreciable air leakage through the unpainted fiberboards. The flanged mouth of the pressure chamber was provided with a flat gasket of ½- by 4-in. sponge rubber, against which the painted surface of the test panel was tightly clamped. Figures 5 and 6 show two finished test panels.

In testing for spurious leakage, the mounted window was sealed over with a sheet of rubberized fabric. The spurious leakage rate measured under this condition did not exceed 0.20 cu ft/min at a pressure of 1.5 in. of water for any of the specimens tested, corresponding approximately to 2 percent of the smallest infiltration rate recorded in the tests.

IV. TEST PROCEDURE AND RESULTS

1. General

Differences in actual dimensions of windows of the same type and stock size give rise to lack

FIGURE 6.—*Double-hung wood window mounted in test panel.*

The face of the panel showing in the photograph is exposed to the atmosphere during test.

of agreement between the results of infiltration tests, some reported variations being of the order of 100 percent [5]. Substantially all this variation can be traced to differences in width of the gap between stationary and movable members of windows, and it is recognized that test results on windows in which clearances are not accurately known or are subject to variation during test have small value for comparative purposes. Referring the infiltration measurements to fixed clearances measured at the time of the test would be expected to reduce the uncertainties which are due to indeterminate clearances.

In order to determine the effect of sash clearance as a factor in window infiltration, some investigators [5, 6] have conducted infiltration tests on windows for a number of graduated clearances, and in some cases, using double-hung wood windows [5], the tests were conducted with the sash unlocked. Under this condition the sash clearances during the test are indeterminate and have variable values, since both the air pressure and the friction at the edges of the sash control sash motion. Irregularities found in curves of infiltration plotted as a function of test pressure with the sash free indicate that, for this condition, accu-

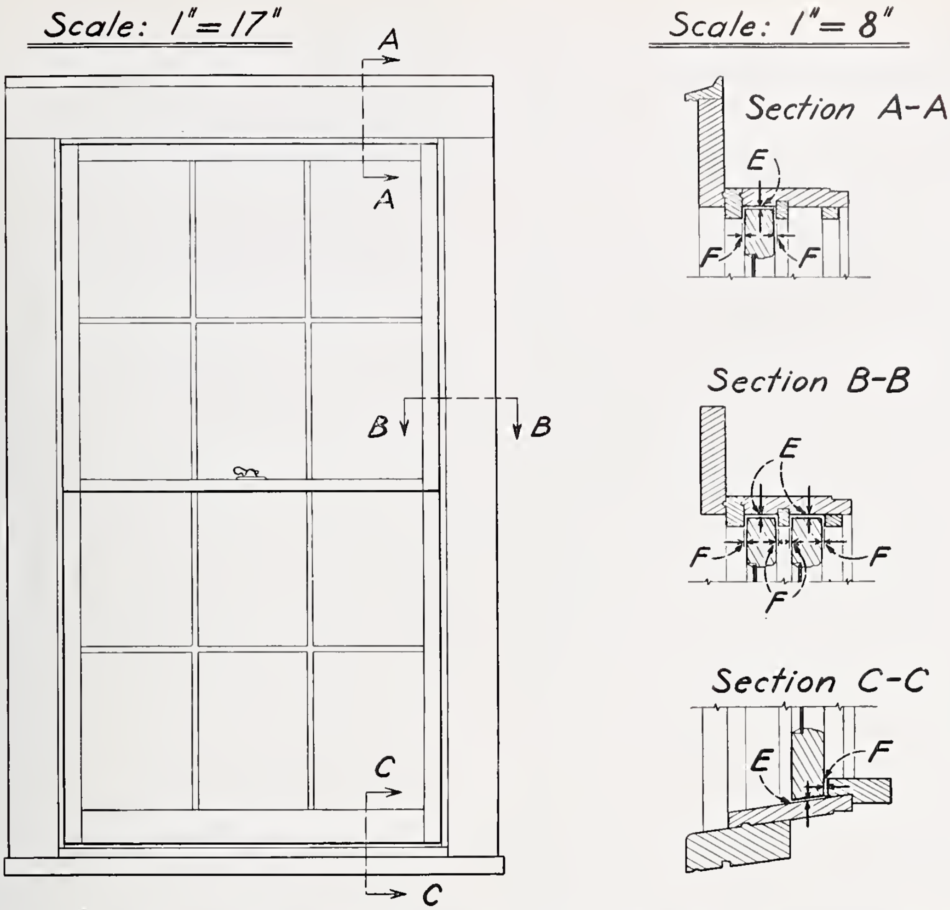

FIGURE 7.—*Detail drawing of double-hung wood windows used in this investigation.*

Gaps measured with feeler gages for computation of average clearances are shown as follows: *E*, edge clearance; *F*, face clearance.

rate control of sash clearances is not realized. The present tests indicate that even with accurate control of sash clearances and accurate gauging, it is difficult to obtain precise agreement of infiltration values for duplicate windows of some types.

In outlining the work of this project it was believed that a correlation of infiltration with clearance widths, under controlled and accurately measured clearance conditions, was desirable. A program of tests was conducted accordingly, using two common types of windows: plain double-hung wood windows and light steel casements.

2. Clearance Correlations, Double-Hung Wood Windows

The clearance between the sash and the frame in double-hung wood windows can be specified by two quantities representing averages for the window as a whole—the average clearance between the sash edges and the parallel inner surface of the window frame, and the average clearance between the faces of the sash and the corresponding surfaces of the stops and parting strip. These two quantities are referred to in this report, respectively, as the *edge clearance* and the *face clearance*, and are illustrated in figure 7, which also illustrates the details of design of the double-hung wood windows tested. Other workers have used the term "crack" to denote the edge clearance and the term "clearance" to denote twice the face clearance.

The commercial description of the windows follows:

Window.—Sash 1⅜ in., with check rail. Twelve lights, each 10×14 in., back-puttied, glazed with S.S.B. window glass. Opening 2 ft 10½ in.×5 ft 2¼ in.

Stiles and top rail 2 in., bottom rail 3 in., check rail 1 in. Bars 3/16 in. between glass, 9/16 in. over-all.

Frame.—One-pulley frame for 2×4 in. stud, with drip cap. Outside casing 1⅛×4½ in. Sill and subsill. Sill 1⅝×4½ in., parting stop ½×¾ in., stool 1⅛ in., blind stop ¾ in. Baltimore opening, 2 ft 10½ in.×5 ft 2¼ in.

Since it was desired to have the gap widths during the tests accurately defined, the test specimens were arranged so that the clearances could be varied and measured, but held fixed during any one test. Three stock windows, of standard opening 2 ft 10½ in. by 5 ft 2¼ in., were supplied by the National Door Manufacturers' Association; two were used in the correlation tests and the third was used for comparative tests under conditions in which the sash were unlocked and free to move between the stops. For the fixed-clearance tests the windows were mounted in test panels as previously described, and the inner strips and parting strips, which act as sash stops, were removed and drilled to receive wood screws with which to refasten them in the frames. They were also drilled to receive machine screws which served as adjustable stops for setting and maintaining face clearances approximately equal to the indoor and outdoor face-clearance gaps. Similar machine screws, passed through frame jamb members and meeting the sash edges at various points, allowed approximate equalization and maintenance of the edge-clearance gaps around the sash. Adjustment of face clearance was obtained by inserting prepared parting strips of suitable widths, and edge clearances were varied by planing material from the edges of the sash—in each case, with appropriate resetting of the machine screws in the frame.

The clearances were never constant around the sash perimeter even when the adjustments were made with great care, and feeler-gage measurements at intervals of 1 in. along the sash perimeter were made in order to secure reliable average clearance values. The variation of clearance width along the sash perimeter is illustrated by the typical set of measurements given in table 2.

The clearances were measured by means of feeler gages inserted at 1-in. intervals around the perimeter of the sash, and along the meeting rail, from both the indoor and the outdoor sides. Access to the edge-clearance gap for gaging was obtained by temporary removal of sash guide members. A set of brass feeler gages ⅜ in. wide, having blade thicknesses of 0.0108, 0.0156 (1/64), 0.0312 (1/32), 0.0469 (3/64), 0.0625 (1/16), 0.0937 (3/32), and 0.1250 (⅛) in. was used. In gaging, the thinnest blade was tried at each station in turn, the number of stations admitting it being recorded. The procedure was repeated using the next larger gage, and each of the other gages in succession. From these data the fraction of the total gap-length (the length of clearance opening around the entire sash) admitting each blade was computed. When the resulting values of the fractional gap-length are plotted against the corresponding gage-blade thickness, the area below the resulting curve gives the linearly interpolated average value of the clearance.

Table 2.—*Variation of clearance along a portion of a sash perimeter—illustrative data for a double-hung wood window*

[The data are from feeler-gage measurements of the indoor face clearance along a side of a sash member in one of the double-hung wood windows used in this investigation.

The numbers in the table denote the feeler-gage stations, which were spaced 1 in. apart along the sash perimeter. The manner of gaging makes it necessary to give ranges within which the actual clearance gap width may lie, rather than the actual value of the width.]

Range of gap width			
0.0156 to .0312 in.	0.0312 to .0469 in.	0.0469 to .0625 in.	0.0625 to .0937 in.
STATION NUMBERS			
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
	11		
	12		
	13		
	14		
	15		
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			30
			31

The average clearance values were obtained using this principle, but instead of graphical determination of the areas beneath the curves, a corresponding formula based on Simpson's rule was used. The observed values of the fractional gap lengths were inserted directly in this formula.[7]

The formula was used to determine separately the edge clearance, the face clearance of the indoor side of the sash, and the face clearance of the outdoor side. The latter two average clearances, denoted the indoor and the outdoor face clearances, were combined into a single quantity, called the face clearance of the window, in a manner intended to accord approximately with the conditions of the air flow through the clearance spaces. This was accomplished by computing the reciprocals of the indoor and outdoor face clearances, averaging the two, and taking the reciprocal of this average as the desired average face clearance. The type of average used is here denoted a "reciprocal average."

It is clear that a simple arithmetical average of the indoor and outdoor face clearances would not provide a correct basis for a correlation of clearance conditions with infiltration, since such an average would give equal significance to a very narrow and a very wide clearance gap in series in the flow. Actually the wide gap must have far less effect on the total resistance, which determines the flow at a given pressure, than does the narrow gap. The theory of flow through narrow channels which is based on the assumption of laminar flow [7] indicates that the type of average for the widths of series channels which is uniquely correlated with the rate of flow is based on the average of the cubed reciprocals of the component gap widths. A first approximation to this reciprocal-cube average, adopted because of the considerable saving in time of computation, is the reciprocal average described in the preceding paragraph. Computations indicate that, in the range of dimensions encountered in the windows to which this method was applied, the maximum deviation of the reciprocal average from the reciprocal-cube average was 3.8 percent, while the maximum deviation of the arithmetical average was 8.7 percent. Although comparison of computed data with the test data indicates that the simple theory of channel leakage based on the assumption of laminar flow does not explain correctly the full range of data on window infiltration obtained in this investigation and that the assumption of laminar flow is somewhat arbitrary, the procedure adopted for reducing the two face clearances of the double-hung wood windows to a single average value is believed to supply a more consistent basis for correlation with infiltration rates than would an arithmetical averaging method.

A typical set of feeler-gage observations for face clearance on a double-hung wood window is shown in table 3 as they would be recorded in the laboratory, together with an illustrative outline of the method of computing the reciprocal-average face clearance from the gage data.

One window of this series was used in developing the test procedure; and as a result of planing down the sash edge in large steps during the development work, an incomplete set of data was obtained for this specimen. Infiltration measurements were made on this window for 14 edge- and face-clearance combinations and for a number of pressures up to a maximum of 0.7 in. of water; but, because of the incomplete form of the data, it was used only in checking the results obtained for the other two specimens.

Using another window of the series, five edge clearances were established, and for each edge clearance tests were made for at least four face-clearance settings. The infiltration was measured for five pressures in the range of 0.16 to 0.24 in. of water for each clearance condition, and the infiltration rates corresponding to a pressure of 0.20 in. of water were interpolated from plots of the data. The infiltration rate for a pressure of 0.20 in. of water is called the *reference infiltration* for a particular clearance condition, and is used subsequently as a specification of the infiltration behavior of the test window under that clearance condition. This simplification was used since it was found that the curves of infiltration plotted against pressure had substantially the same shape and were

[7] The formula derived for the average clearance K in inches, based on measurements with the feeler gages described above, is—

$$K=0.0054+0.0078p_1+0.0102p_2+0.0156p_3+0.0156p_4+0.0234p_5+0.0312p_6+0.0156p_7,$$

where p_1 is the fractional gap-length admitting the thinnest gage, p_2 that admitting the next thicker gage, etc.

TABLE 3.—*Illustration of procedure used in recording feeler-gage data and computing average face clearance for a double-hung wood window*

[The data are from a typical set of measurements on one of the double-hung wood windows studied in the present investigation]

Clearance region: Sash	Clearance region: Side	Number of stations	Gage thicknesses, inches: 0.0108	0.0156	0.0312	0.0469	0.0625
OUTDOOR							
			Gage counts				
Upper	Left	31	15	14	9	2	------
	Right	31	10	6	------	------	------
	Top	34	34	34	32	17	8
Lower	Left	31	7	3	------	------	------
	Right	31	9	2	------	------	------
Totals (*A*)		158	75	59	41	19	8
Formula coefficients[a] (*B*)		--------	0.0078	0.0102	0.0156	0.0156	0.0234
Products (*A*×*B*)		--------	.585	.602	.640	.296	.187
Sum of products, 2.310. Divide by crack length (158 in.): 0.0146. Add first formula coefficient[a] (0.0054) for clearance: 0.0200 in.							
INDOOR							
			Gage counts				
Upper	Left	30	20	18	------	------	------
	Right	30	30	30	20	6	------
	Top	34	9	4	------	------	------
Lower	Left	32	0	------	------	------	------
	Right	32	2	------	------	------	------
	Bottom	34	11	4	------	------	------
Totals (*A*)		192	72	56	20	6	0
Formula coefficients[a] (*B*)		--------	0.0078	0.0102	0.0156	0.0156	0.0234
Products (*A*×*B*)		--------	.562	.571	.312	.094	----
Sum of products, 1.539. Divide by crack length (192 in.): 0.0080. Add first formula coefficient[a] (0.0054) for clearance: 0.0134 in.							

Reciprocals of the outdoor and indoor face clearances: 50.0, 74.6. Average of reciprocals, 62.3. Reciprocal of latter gives desired "reciprocal-average" face clearance: 0.0160 in.

[a] The formula coefficients referred to are those given in footnote 7 of the text.

reducible to a type form with reasonable accuracy by the application of a constant factor to the vertical scale. The procedure is discussed in detail in section IV–3 of this report.

The results of the tests on the second window are shown plotted in figure 8, where the reference-infiltration face-clearance curve has been drawn for each edge clearance. Some of the data obtained using the other two windows have been plotted for comparison.

Data giving the relation between infiltration for the fixed-sash condition and the free-sash condition, represented by a closed unlocked window, were obtained using the third specimen. By means of adjustments similar to those made in the case of the second window, clearance conditions were set up for this window approximating those represented by the term "average practice" for double-hung wood windows. The "average practice" conditions, determined as a result of field surveys [5], correspond to 0.0625-in. edge clearance and 0.0234-in. face clearance. After data for plotting an infiltration curve had been obtained for the sash-free condition (that is, sash not locked or centered), the sash were locked and centered as in the tests on the second window and infiltration measurements made under controlled clearance conditions. The gage measurements given in table 4 are illustrative of the uncertainties encountered in obtaining desired clearance conditions with the sash free. [8]

TABLE 4.—*Measured average clearances with sash free and fixed—double-hung wood window No. 3*

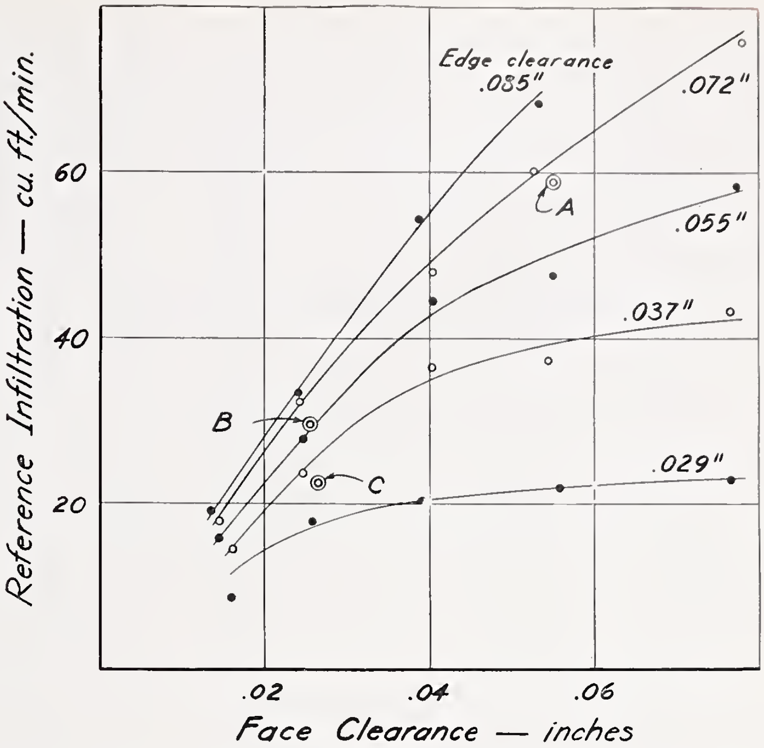
	Sash free	Sash fixed
Face clearance ....inches..	0.021	0.025
Edge clearance ....inches..	.064	.060
Reference infiltration ....cu ft/min..	26.7	29.6

Figure 9 shows infiltration curves for the fixed-sash condition and the free-sash condition. Since the fixed-sash clearances could not be accurately duplicated with the sash free, it is impossible to ascribe the difference between the measured infiltration rates for the two conditions entirely to the effect of the permitted sash motion. However, these tests indicate the order of magnitude of the difference in infiltration behavior to be expected between the two conditions. For example, the test results show that, although the greatest difference in clearance between the two conditions was about 20 percent and, therefore, unlikely to be responsible for any very great difference in infiltration behavior, the measured infiltration for the sash-free condition was only about 5 percent less than that for the fixed-sash condition at the reference pressure of 0.200 in. of water. At higher pressures the relative difference in infil-

[8] In the case of the sash-free condition, it was found impossible to obtain consistent clearance data by the method of gaging used in the tests on windows with locked and centered sash, since any very slight motion of the sash in the space between the stops as a result of gage contact might entirely change the distribution of clearances and thus affect the average-clearance results. Hence the clearance data given for the sash-free condition were obtained by dividing in half the "double clearance" measured with the feeler gage when the sash was displaced by pressure of the hand until it rested against the frame members which limit its motion.

Figure 8.—*Effect of face and edge clearance on reference infiltration—double-hung wood window No. 2, sosh fixed. (Sash perimeter 19 ft.)*

The points plotted for comparison are as follows: *A*, double-hung wood window No. 1, sash fixed, average edge clearance 0.064 in. *B*, double-hung wood window No. 3, sash fixed, average edge clearance 0.060 in. *C*, double-hung wood window No. 1, sash fixed, average edge clearance 0.027 in.



trations for the two cases was larger. The relatively close agreement in the data for the fixed and free sash at reference pressure might, however, not be found with clearances widely different from those set up in these tests.

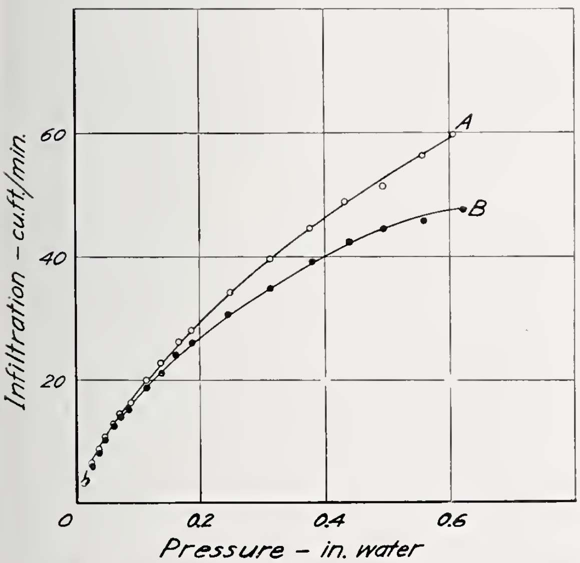


Figure 9.—*Comparison of infiltration curves using fixed and free sash—double-hung wood window No. 3, "average practice" conditions.*

A, sash fixed; *B*, sash free.

3. Clearance Correlations, Light Steel Casements

Steel casement windows have been standardized by manufacturers as to general design and as to the weight of the rolled-steel members from which they are fabricated. The structural-member size designated as "light" is the most widely used for casement windows in low-cost housing construction. The general design of these windows provides two weathering contacts, but since these are not independently adjustable as in the case of double-hung wood windows, a single average clearance may be used to specify the clearance condition of a window of this type.

The original clearance of a light steel casement in service may become altered by deformation of the structural members or lodgement of solid matter along the weathering contact surfaces. Resulting clearance conditions may be simulated approximately for the measurement of air leakage by placing shims against the weathering contact surfaces in such a way that when the window is closed and fastened the average clearance is increased from that corresponding to the origi-

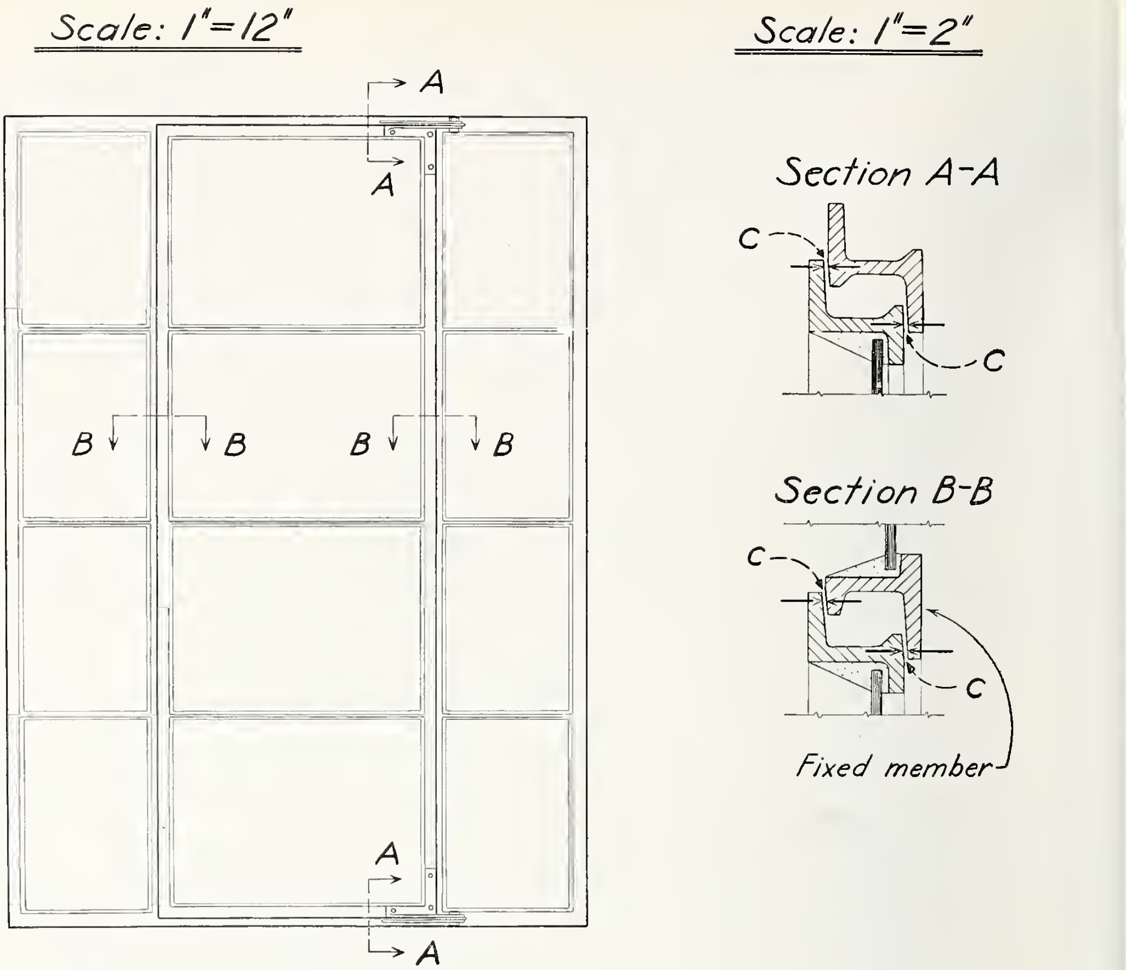


FIGURE 10.—*Detail drawing of the light steel casements used in this investigation.*

Gaps measured with feeler gages for computation of average clearance are shown at points *C*.

nal locked-shut position by a desired amount.

The two specimen windows used in these tests were light steel casements supplied through the Metal Window Institute. The details of their design are shown in figure 10.

The two test specimens are of the "light casement housing window" type, 3 ft. 1½ in. by 4 ft. 4¾ in. over-all, and are designated type 4418VC with vertical muntin omitted. They are three lights wide with glass widths of approximately 8 in. at the two sides and 16 in. at the center. In height there are four lights, each approximately 12 in. The vertical center portion is the ventilator and is side hinged to open the full height of the unit.

The casements are constructed of solid hot-rolled steel sections designed for manufacture of casement windows. The framing and ventilator bars are 1 in. deep front to back and ⅛ in. thick. Muntins are approximately ⅝ in. in depth and on the face.

The ventilator meets the framing members with a continuous two-point flat contact extending around the ventilator. Two extension friction hinges are used. For locking, the ventilator is equipped with a cam handle. Glazing is with single-strength grade *B* window-glass set in bed and face putty and held by spring-wire glazing clips.

The shims for setting the desired clearances were sheet-brass strips of various thicknesses, ¼ in. wide, placed between the indoor weathering contacts in at least two locations on the locking-handle side of the ventilator. The method of gaging was similar to that previously described for double-hung wood windows. The gage was a standard machinist's set having a width of about three-eighths inch.[9] The blade

[9] The set of gages used with the double-hung wood windows and described in section IV-2 of this report was found unsuited for use with the steel casements because, in order to meet desired accuracy tolerances, a set of gages proceeding by smaller intervals of thickness was required. The gage described above was therefore selected. The formula for computing the clearance, K, using this gage, is—

$$K=0.0025+0.005\ (p_1+p_2+p_3+\ .\ .\ .).$$

The symbols here have the same meanings as those given in footnote 7.

thicknesses used were 0.005, 0.010, 0.015, 0.020 in., etc., each blade being inserted between the edge of the ventilators and the frame until a blade was found which would not pass at any of the gage stations marked at 1-in. intervals around both the indoor and the outdoor surfaces of the ventilator member. The number of stations at which each gage was admitted was recorded separately for indoor and outdoor window surfaces and for the four sides of the ventilator. These sides will be referred to as top, bottom, hinge side, and locking-handle side.

The method of averaging the clearance data so as to obtain a single quantity characterizing the clearance condition of the window was developed on the basis of the flow-resistance conditions for narrow channels in series [7]. In this method the average clearance was first computed, in the manner described in section IV–1, for each portion of the ventilator separately, that is, top indoor, top outdoor, hinge side indoor, hinge side outdoor, etc. The clearances for two corresponding contact surfaces directly opposite each other through the window, for example the top indoor and the top outdoor surfaces, were combined by computing the reciprocal of the average of their respective reciprocals, thus obtaining in this case an average clearance for the top of the window. The resulting figures for the four boundaries of the window, weighted by the crack length of each, were then combined to give the mean clearance for the window as a whole. A numerical example is given in table 5. The infiltration-clearance plots which were made using the reciprocal-formula average of the indoor and outdoor clearances at each station show somewhat smaller average deviations of the data than those made using the arithmetic average.

Infiltration measurements were made for various pressures in order to plot the infiltration-pressure curve for each clearance condition of each specimen window. The clearance conditions included the original unaltered clearances of both windows when locked, and five clearances set by means of shims, for each window. The infiltration at a pressure of 0.20 in. of water was interpolated on the infiltration-pressure curves, as in the case of the double-hung wood windows, and was used as the *reference infiltration* for a specified condition in the computations. When the values of reference infiltration and clearance were plotted, as shown in figure 11, substantial agreement of the data for the two windows was observed; and for this reason the curve has been drawn to represent the entire set of data points obtained for both specimens. The average deviation of the values of the reference-pressure infiltration from the corresponding values given by the smooth curve is 5.5 percent, based on the data obtained for both windows.

Table 5.—*Illustration of procedure used in recording feeler-gage data and computing average clearance for a steel casement window*

[The data are from a typical set of measurements on one of the light steel housing casements studied in the present investigation]

Clearance region: Surface	Clearance region: Side	Number of stations	Gage thicknesses, inches: 0.005	0.010	0.015	0.020	0.025	0.030	Total number of counts	Region clearance[a]
			Gage counts							
										in.
Outdoor	Top	16	2						2	0.0031
	Handle	50	50	38	14	3	2	1	108	.0133
	Bottom	15	15	15	11	8	6		55	.0208
	Hinge	50	43	20	6				69	.0094
Indoor	Top	17	3						3	.0034
	Handle	49	25	6	4	1			36	.0062
	Bottom	17	17	9	2				28	.0107
	Hinge	47	29	5					34	.0061

Computation of reciprocal-formula average clearance from the region clearances given above:

Combined clearance region	Reciprocals of region clearances: Outdoor	Reciprocals of region clearances: Indoor	Average of reciprocals, A	Reciprocal of averages, $1/A$	Region weight,[b] L	$(1/A)\times L$
Top	323	294	309	0.0032	33	0.106
Handle	75	161	118	.0085	99	.842
Bottom	48	93	71	.0141	32	.451
Hinge	106	164	135	.0074	97	.718
Sums					261	2.117

Dividing the aggregate weighted reciprocal-average clearance (2.117) by the total of the region weights (261), the reciprocal-average clearance for the window as a whole is obtained: 2.117/261=0.0081 in.

[a] Found by use of the formula given in footnote 9 of the text. Illustrating: For a gage count total of 108, and a region length (that is, number of stations) of 50, the region clearance is
$$0.0025+0.005\times 108/50=0.0133 \text{ in.}$$

[b] Consists of total crack length of region for both surfaces, that is, the sum of the number of stations on outdoor and indoor surface of the region.

In investigations at other laboratories in which shimmed clearances were set up [6], a somewhat different method of denoting clearances has been used, the thickness of the shim inserted between the contacts of the locking-handle side of the ventilator being given directly as the clearance.

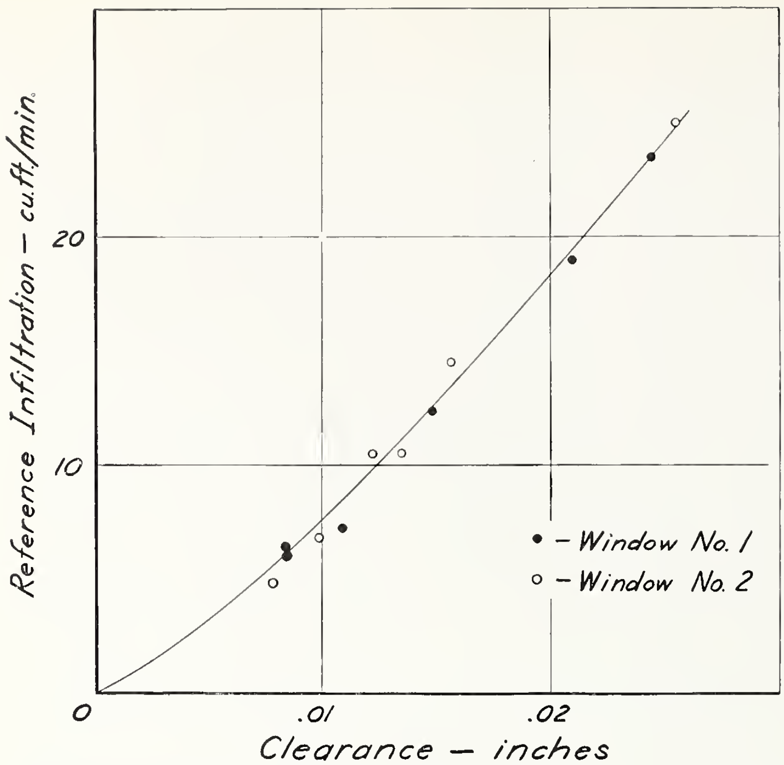


FIGURE 11.—*Effect of clearance on reference infiltration—light steel casements.* (*Sash perimeter 11 ft.*)

The curve was drawn for all the points obtained for both specimens.

This definition of clearance assumes the straightness of the members and uniformity of the clearance for the entire periphery of the ventilator. Distortion of the members may take place in the forming process or in fabricating the frame. Such irregularities, although usually controlled by gaging and adjusting at the factory, may be sufficiently large and numerous to represent an appreciable fraction of the average clearance. In addition, the geometry of construction of hinged ventilators, as in the case of a hinged plate, is such that opening the ventilator gives rise to nonuniform crack width. For example, in a partly open side-hinge ventilator the top and bottom gaps are approximately trapezoidal while the hinge-side and handle-side gaps may be represented by rectangles having unequal areas. For these reasons it appeared desirable to use average values based on actually measured values of crack width rather than values of shim thickness. Figure 12 gives average clearance measurements made on one of the windows and figure 13 gives a comparison of the average clearance for the entire perimeter of both windows with those obtained by the same method for the open sides only.

4. Correlation of Infiltration and Pressure

In computing infiltration, it is desirable to have data relating both wind speed and sash or ventilator clearance to infiltration, since both of these factors are subject to variation. The relation between wind speeds and the static pressures used in laboratory infiltration tests has been discussed in this report. In addition, relationships between static pressures applied to windows in laboratory test equipment and the resulting air-leakage volume must be established. Because of the presence of so many variables, simplification of the expressions representing window performance is desirable as a means of reducing the number of steps in heating-load computations.

Attempts have been made to represent the experimental infiltration-pressure relationships using mathematical formulas. The results of many tests indicate that the type of curve predicted by the theoretical formula for orifice flow—

$$I = \text{constant} \times \sqrt{p},$$

cannot be made to represent the data over the full range of pressures ordinarily used. This is also true of the formula for capillary flow—

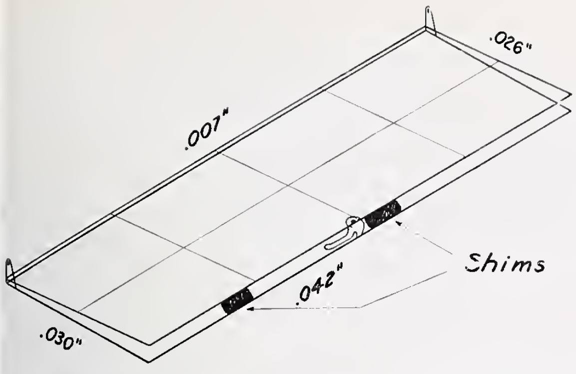


FIGURE 12.—*Schematic drawing showing one distribution of measured clearances for a light steel casement.*

Values shown are averages for indoor and outdoor weathering contacts. The over-all average clearance for the window was 0.025 in.

$$I = \text{constant} \times p,$$

where I represents the infiltration and p represents the pressure. Most of the infiltration-pressure curves examined in the course of the present investigation were found to have shapes intermediate between those of the linear and the square-root theoretical curves. Sigwart [8] represented the relationship using expressions of the form $I = Cp^n$, where n has a value in the neighborhood of 0.75. Such a formula is somewhat inconvenient to use.

To simplify the presentation and use of the infiltration-pressure relation for various windows, it was found useful to express the results in terms of *infiltration ratios*. The infiltration ratio at a given pressure, for a window under specified clearance conditions, is defined as the ratio of the infiltration of the window at that pressure to the infiltration at the reference pressure of 0.200 in. of water, with the other conditions the same. It was found that, for a large range of types and conditions of windows, the curves of infiltration ratio plotted against pressure were in approximate coincidence over a pressure range from zero to about 0.60 in. of water.

In order to investigate this indicated agreement further, a curve of average infiltration ratios, computed from 36 tests on two double-hung wood windows and two light steel casements, was constructed. This curve is shown in figure 14, and is denoted the *over-all average curve*. Points representing separately the average infiltration ratios for the double-hung wood windows and for the light steel casements are also shown in the figure. The average deviation of the original test data from the over-all average curve is 4.1 percent for the pressure range between zero and 0.60 in. of water.

Figure 15 shows infiltration-ratio values plotted from data obtained using windows of miscellaneous types which were submitted to the National Bureau of Standards for test in connection with this project. The over-all average curve, obtained as described above, has been drawn in for comparison. Average deviations for the values shown in figure 15 from the over-all average curve are:

	Percent
Light double-hung steel, locked	4. 4
Wood casement of special design	2. 7
Standard double-hung wood, sash free (unlocked)	3. 7
Heavy-section steel casement	10. 8
Medium weight double-hung steel (locked)	4. 3

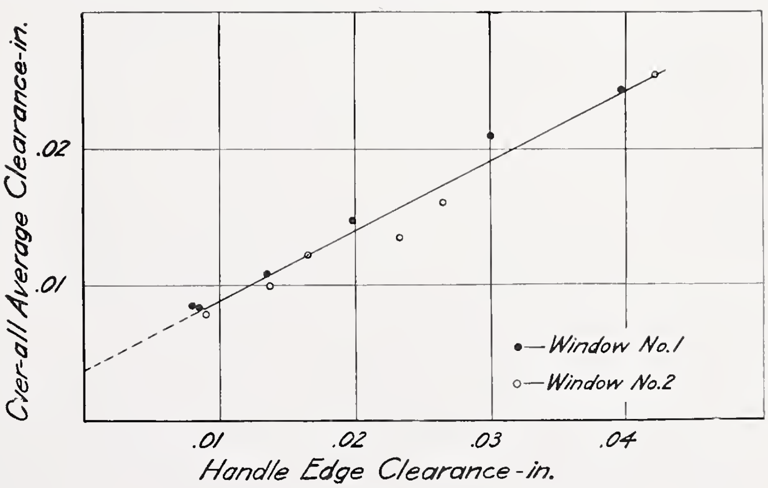


FIGURE 13.—*Relation of the over-all average clearance for the light steel casements used in this investigation to the average handle-edge clearance.*

The values of over-all average clearance are based on 261 measurements, and those of average open-edge clearance on 97 measurements, for each window.

With the exception of the heavy-section steel casement, the infiltration behavior of the windows, including some of special design, is represented to within 5 percent by the over-all average curve derived from the measurements made on fixed-sash double-hung wood windows and light steel casements.

Values of the infiltration ratio obtained from the over-all average curve are given in convenient form in table 6.

TABLE 6.—*Tabular form of over-all average curve of infiltration ratio derived from infiltration tests on light-steel casements and fixed-sash double-hung wood windows*

[The values of wind speed given were computed from the formula $V=\sqrt{q/0.000481}$]

Pressure,	Wind speed	Infiltration ratio
Inches of water	*Miles per hour*	
0.05	10.2	0.38
.10	14.4	.63
.15	17.7	.82
.20	20.4	1.00
.25	22.8	1.15
.30	25.0	1.30
.35	27.0	1.43
.40	28.8	1.55
.45	30.6	1.67
.50	32.2	1.78
.55	33.8	1.88
.60	35.3	1.98
.65	36.8	2.06
.70	38.2	2.12

The data given in table 6 or the corresponding curve (fig. 14) may be used within the limits of error usually acceptable in design computation to estimate the infiltration for windows of the types tested at any pressure within the range zero to 0.60 in. of water, provided the infiltration at any other pressure within the range is known. The applicability of these results has been verified for a substantial number of window types and clearance conditions.

V. COMPARATIVE RESULTS

1. WOOD WINDOWS

Reports of infiltration tests of wood windows from other laboratories do not give the detailed methods used in determining clearances. The clearances stated in the present report are averages determined as previously described from measurements at 1-in. intervals for the entire periphery of each window, comprising 192 observations for each edge clearance and 384 observations for each face-clearance setting.

Comparisons of the results obtained in the present tests with those of other workers under similar conditions are therefore very difficult, since the edge and face clearances for a given crack length and applied pressure are the controlling factors in infiltration and their values must be accurately known. The values of infiltration obtained in the present tests are from 60 to 100 percent greater than the average

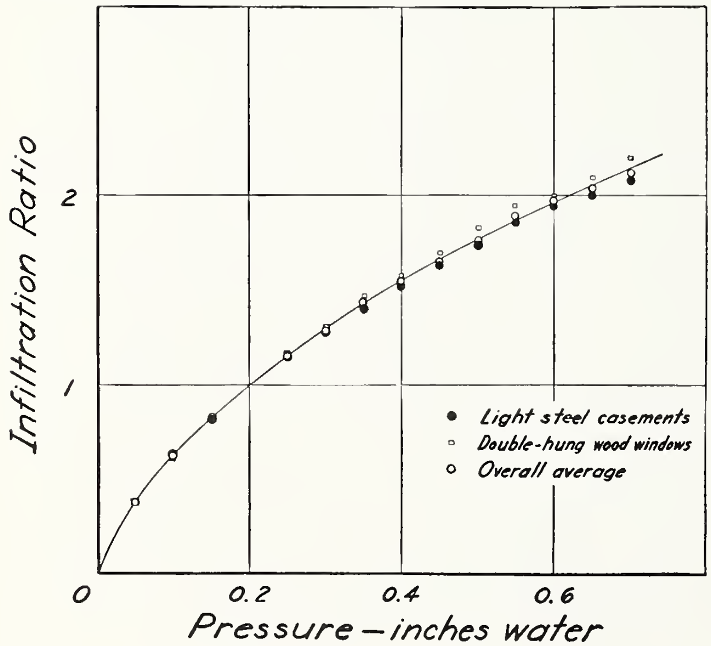
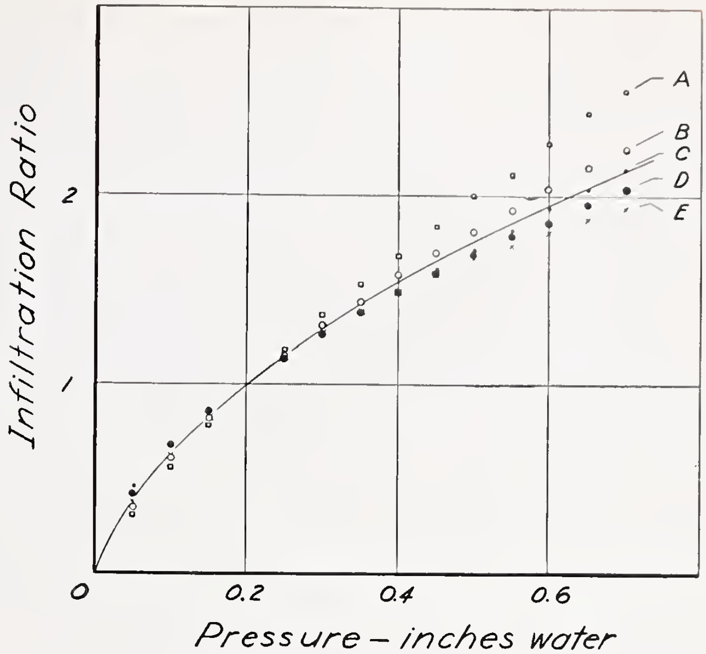


FIGURE 14.—*Curve of infiltration ratio.*

The curve was drawn for the over-all average points only. The points for double-hung wood windows are those obtained for the fixed-sash condition.

FIGURE 15.—*Comparison of infiltration ratios.*

The curve shown is the over-all average curve. (See fig. 11.) *A*, heavy-section steel casement. *B*, wood casement of special design. *C*, medium steel double-hung window, locked. *D*, light residential steel double-hung window, locked. *E*, double-hung wood window with sash free.



values given in reference [5] for the same nominal clearance. However, the results given in reference [5] include only one combination of edge and face clearance (1/16-in. edge, 3/128-in. face) within the range of the present tests, one combination (3/32-in. edge, 3/64-in face) for which extrapolation of figure 8 appears reasonably safe, and a third combination (1/64-in. edge, 1/64-in. face) for which extrapolation appears unreliable.

The discrepancy in absolute values of infiltration rates is believed to be due to uncertainties in the equivalence of the clearances. The infiltration ratios for different pressures in reference 5 do not differ greatly from ours, as shown by the comparison of figure 16.

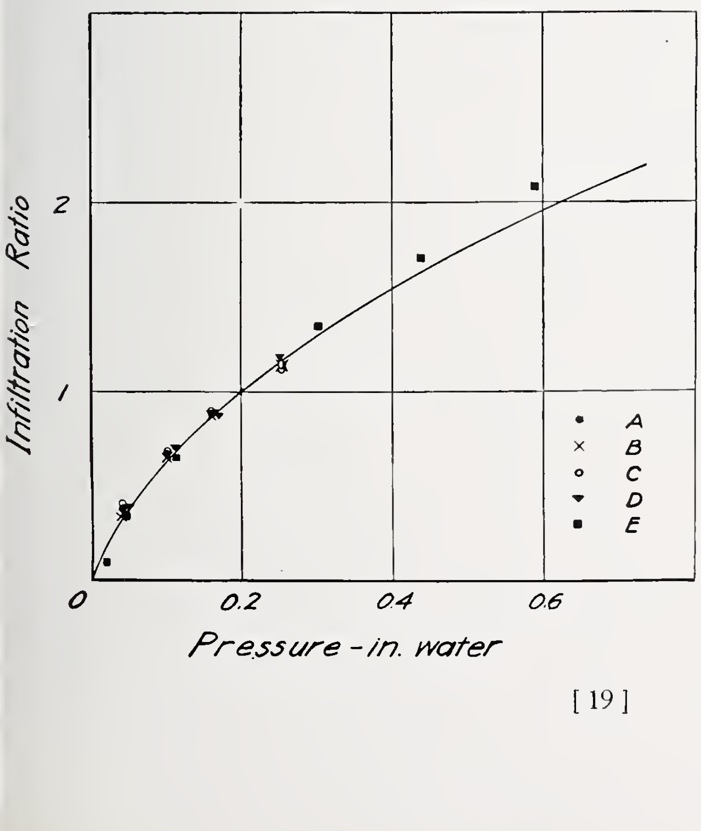


FIGURE 16.—*Comparison of infiltration ratios.*

The plotted points represent ratios computed from infiltration rates obtained by several investigators for various types of windows. The solid curve represents the data obtained in the present investigation, and is reproduced from figure 14. *A*, residential steel casement. *B*, heavy casement, projected. *C*, industrial, horizontally pivoted. *D*, commercial, horizontally pivoted. *E*, double-hung wood window. The values for points *A*, *B*, *C*, and *D* were computed from data given in reference [6]; the values for *E* were computed from data given in reference [5] for nine unweatherstripped wood windows.

2. Steel Casement Windows

The results for the steel casement windows obtained in the present tests are in good agreement with the results of Emswiler and Randall [6] for the same type of windows when allowance is made for the difference in the methods of stating the clearance.

Attention has previously been called to the fact that because of the geometry of the construction of hinged casement sash the thickness of shims placed along the open edge of the sash does not accurately specify average clearance. When shims are placed in the crack along the open edge of the ventilator, the open-edge clearance is equal to the shim thickness if the meeting edge members are straight and parallel to each other. However, the shim thickness does not represent the average clearance of the whole ventilator even though straightness and parallelism of all meeting members is assumed, as may be seen from figure 12. To obtain a basis for comparison, values of the average clearance at the open edge are plotted in figure 13 against the average clearance for the whole ventilator, the data being obtained in the present study. Each clearance value for the whole ventilator was obtained from gage measurements at 132 points on the sash.

Assuming the average open-edge clearance equal to the shim thickness given by Emswiler and Randall [6], the results are compared with those given in this paper in figure 17. The agreement is very good. The infiltration ratios at different pressures are also in good agreement, as shown in figure 16.

VI. SUMMARY

The infiltration test equipment described in this report has been found to give reliable and consistent results. Essentially, the equipment consists of a source for supplying air, a storage tank, an integrating meter for flow measurement and a semiautomatic timing system. A special test-panel construction and sealing compound were developed and used to insure minimum spurious leakage during tests.

To illustrate the use and performance of the equipment, results of tests on double-hung wood windows and light steel casements, under controlled and accurately measured clearance conditions, are given. Since infiltration results are greatly influenced by the method used in setting and determining sash clearances, it is believed the data based on actual measurement of clearance rather than on shim thickness are representative of window performance. However, where comparison on a common basis is possible, the results are in line with accepted infiltration data determined by various other methods of measuring clearances. The correlation results for light steel housing casements are considered to be representative for windows of this class if

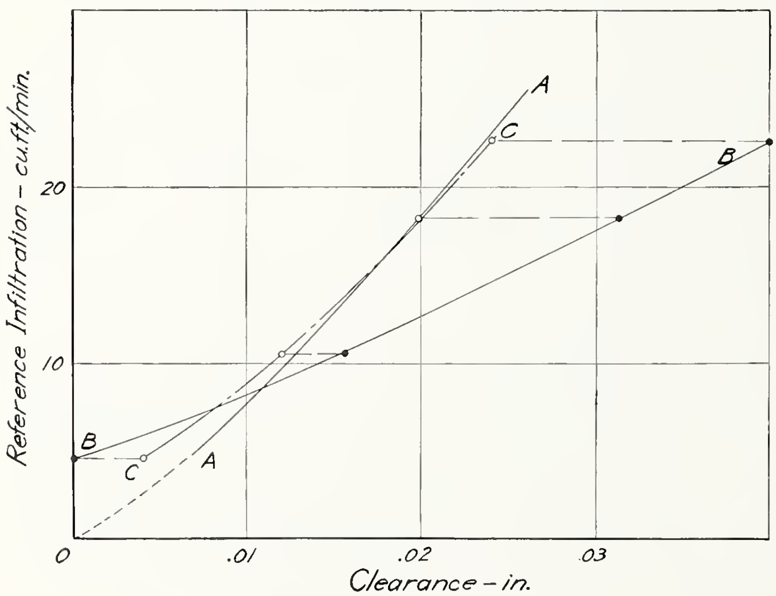


Figure 17.—*Comparison of data obtained in the present tests on light steel casements with data given for residential steel casements in reference [6].*

In comparing the data, the thickness of shims placed along the handle-side edge of the ventilator is assumed to be represented by the average measured clearance of the handle-side edge. Curve *A*, reproduced from figure 11. Curve *B*, reference infiltration data from reference [6] plotted on basis of stated clearances, that is, handle-edge shim thicknesses. Curve *C*, same reference infiltration data as for curve *B* plotted on basis of over-all average clearance corresponding to the stated clearances in reference [6].

the over-all average sash clearance, determined as described in this report, is used. For double-hung wood windows, because of the number of variable factors involved, the results given are not considered applicable unless the method described in this report for setting and gaging the sash clearances is used.

A concise method of representing the relation between wind pressure and infiltration has been given, an average infiltration-ratio curve being suggested as giving a convenient means of reducing test data for common types and clearance conditions of windows. However, application of the method to other types of windows or for higher test pressures may require the use of a different average curve.

The cooperation of the National Door Manufacturers Association and the Metal Window Institute in supplying specimen windows for the correlation tests and miscellaneous technical information is acknowledged. Acknowledgment is also made of the assistance rendered in connection with this project by D. I. Steele and Nathan Kantor, members of the staff of the Bureau.

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